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Completion Report

Application and Evaluation of the Gospel Hump SNOWSED Model on a Small Forested Watershed

Forest, Wildlife and Range Experiment Station

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INTRODUCTION

Man is continually placing demands on the environment to support the ever changing needs of society. In many cases, these demands create a conflict between environmental concerns and developmental needs which often produce the perplexing question: "Can continued development and environmental integrity coexist or must one be sacrificed for the other?" (Kimball 1979). Today's land manager has the task of conserving for present and future use the diversity and integrity of biotic communities within natural ecosystems, while continuing to meet the demands of society (Gilbert 1979).

Forest land managers are mandated to provide a continual supply of wood for various uses while conserving and protecting the water resource. One important key to understanding this task is the realization that forest streams are not separate and distinct from the land they drain, but are an integral part of the forest ecosystem (Brown 1980). Soil disturbances associated with road construction and subsequent silviculture activities in the Pacific Northwest have high potential for impacting the stream hydrograph and instream sediment transport and deposition.

The potential impacts of silviculture activities on the water and soil resource have been well documented in the past few years. However, the ability to predict with reasonable accuracy the degree of these impacts, such that forest managers can formulate realistic and short- and long-term planning goals, is presently in the developmental stages. Various types of mathematical models, ranging from simple linear regression functions to more sophisticated simulation programming and physical process models, have been developed to attain predictability

for assessing the impact of silviculture practices on the local streamflow and sediment flux on a forest management unit. Quantitative estimates of these impacts are necessary to adequately assess the effects of various land use activities on the soil and water resource.

State-of-the-Art in Modeling

Three basic types of mathematical models have been developed to simulate the effects of forest management on water quantity and quality. These types include:

1. Regression Models
2. Simulation Programming Models
3. Physical Process Simulation Models

Regression models utilize statistical procedures to develop predictor capabilities (e.g., Universal Soil Loss Equation). This method generally lacks the specificity needed to adequately reflect the integrated effects of different management activities. Also, prediction of time and space dependent processes is difficult to obtain with this type of modeling.

Simulation programming employs lumped parameter methodology for determining input/output relations. The general process approach used with this method often lacks physical significance and/or often excludes the important process mechanisms. Internal calibration is usually required for simulation programming to be effective. Development of reliable predictability for a series of management alternatives or mixes of alternatives is difficult to obtain with this approach.

Physical process simulation models based on mathematical functions which represent the processes controlling water and sediment movement are generally considered superior to other types of models. This type of modeling has the potential for providing an analytical/quantitative examination of the streamflow-sediment yield relationship. Physical

process models use information that can be directly related to observable and measurable field characteristics, thus providing the opportunity for site specific and/or integrated simulation of the time-dependent responses of watersheds to multiple use management practices.

Model Selection Criteria

The selection of a representative simulation model for predicting water and sediment yields from forested watersheds should include the following criteria (Mulkey 1977):

(1) utilization of the physical processes which govern water and sediment movement on the watershed;

(2) simulation mechanisms need to be an integral part of the model to define the systems of ungauged watersheds;

(3) analytical and numerical mathematical solutions which provide time and space simulation should be included in the model;

(4) the model should be modular in structure; thus, permitting adaptation to site specific situations with minimal difficulty;

(5) the model needs sufficient simplicity in data inputs and model operation to permit utilization by the practicing professional at the management level.

The purpose of this project was to apply a physical process model (SNOWSED) which simulates water and sediment movement in a small forested subwatershed located in the Horse Creek Administrative-Research study area.

The objectives of this study were to apply and calibrate the SNOWSED model on a small forested watershed using existing climatic and hydrologic data. Secondly, to determine which parameters or subroutines need adjustments or modifications to improve model performance on small watersheds and to evaluate the sensitivity of the

model in the context of the degree of changes in simulated sediment flux and streamflow as related to perturbations in selected input variables.

DESCRIPTION OF SNOWSED MODEL

SNOWSED is a complex deterministic model developed for the USDA Forest Service by the Engineering Research Center, Civil Engineering Department, Colorado State University (Simons et al. 1981a). The model simulates the disposition of rain and snowfall and water and sediment movement from a series of watershed planes into and through defined stream channel segments. The model is comprised of three major hydrologic components. The soil moisture balance component considers changes in soil moisture as related to the volume of precipitation, infiltration, evaporation and transpiration of plants to estimate the volume of water available for surface or subsurface flow. The land surface component determines the rate of surface and groundwater flow, erodibility of the soil, raindrop erosion and the associated protection effects by vegetation and ground cover. This component routes the water and sediment generated from the watershed planes to the third major component. The stream channel component routes water and sediment from the planes through channel segments to some defined downstream station. The sediment and flow data generated in this component also are used to characterize changes in stream channel morphology as a result of variations in water and sediment inflows.

Model Structure

The SNOWSED model was developed from three existing physical models. The model for simulating runoff from rainfall events on small

watersheds (Simons, Li and Eggert 1976) and the infiltration and subsurface flow routing process model developed by Li, Simons and Eggert (1976) were linked with a model developed by Leaf and Brink (1973) which simulates snowpack accumulation and melt. These models were integrated into a compatible computer based model which has the capability of simulating daily water and sediment yields from a drainage on a yearly basis.

The model is divided into seven main programs: SNOWMELT, SNOWSORT, OVERLANDFLOW, TIMESPACESORT, CHANNELROUTE, DISTRIBUTE and RELATIONS. An information flow chart of these programs is presented in Figure 1. Brief descriptions of the functions of these programs are presented in this report. Detailed explanations of programming logic and mathematical functions used in the model are presented in Simons et al. (1981a and 1981b).

The SNOWMELT program simulates snowpack accumulation and melt as related to the energy balance on a watershed surface. The snowmelt water generated in this program is sorted into a matrix of daily melt histograms in the SNOWSORT program. This program also partitions rainfall events into daily histograms. Output from SNOWSORT is internally input in binary form to the OVERLAND FLOW program. Surface and subsurface flow and surface sediment detachment and transport capacity are determined within OVERLAND FLOW. Infiltration response to snowmelt and rainfall is calculated and excess water is partitioned into surface and subsurface flow components which are routed to the channel. Kinematic wave routing methods are used for the two flow components. Analytical methods are used to solve the overland flow routing equations and finite difference approximation for the subsurface

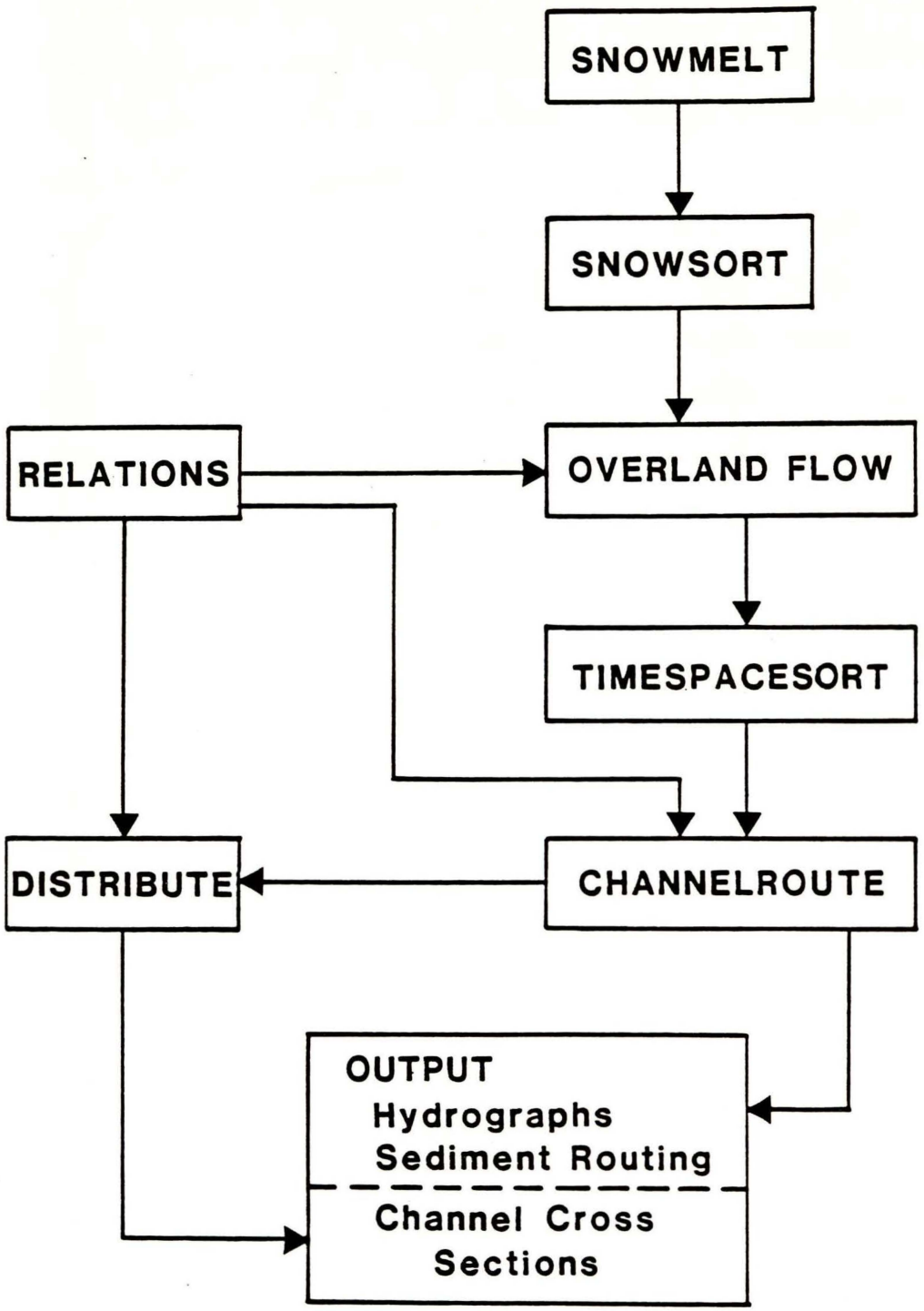

Figure 1. Flow chart of SNOWSED programs.

flow routing equation (Simons et al. 1981a). Surface erosion rates are estimated in this program in conjunction with the overland flow hydrograph. Sediment detachment and transport capacity are estimated using tractive force process equations.

Daily plane hydrograph and sediment yield data produced in OVERLAND FLOW are placed into sequential time and space arrays in the TIMESPACESORT program. CHANNELROUTE uses this information via internal transfer to route water and sediment through the channel segments. A numerical kinematic wave routing scheme is used to route daily water and sediment through the channels to a defined downstream point. Channel sediment detachment and transport capacity are estimated in this program with the same functions used in surface calculations. Output from this program is in the form of water and sediment for designated time steps in a day, mean daily flow and sediment yield, plus monthly and annual summaries of these parameters.

Sediment detachment-transport-deposition information from CHANNEL ROUTE is linked with the DISTRIBUTE program where the degree of aggradation-degradation at defined cross sections is determined in terms of depth of sediments deposited or removed.

The RELATIONS program uses actual channel cross-section geometry to compute the coefficients of the power functions for channel flow area, wetted perimeter and top width relationships which are used in the OVERLANDFLOW and CHANNELROUTE programs. The α_1, β_1, α_2, β_2 coefficients are determined for the functions

$$P = \alpha_1 A^{\beta_1} \tag{1}$$

and

$$T = \alpha_2 A^{\beta_2} \tag{2}$$

where P = wetted perimeter, A = flow area, and T = top width of flow. Values for these parameters are calculated for each channel segment included in simulation. If field data for channel geometry are not available this program can be bypassed and estimates of these coefficients can be directly input into the above programs.

Six of the seven main programs were tested in this study. The DISTRIBUTE program was not included in testing of this model on the small subwatershed.

DESCRIPTION OF STUDY AREA

The watershed selected for model testing is located within the Horse Creek Administrative-Research study area (Figure 2a). Climatic and hydrologic data have been monitored on the Horse Creek drainage and adjacent sub-watersheds for several years. Subwatershed 6 (WS6) is a south facing watershed which drains into the Main Fork of Horse Creek (Figure 2b). Elevation of the watershed ranges from 4240 feet at the mouth to 5660 feet at the ridgetop. Average slope is 33 percent, with shallower slopes present near the mouth and steeper slopes in the upper portions of the watershed. The 256 acre elongated shaped watershed is 1.28 miles in length with a maximum width of 0.46 miles. The total length of the two first-order and one second-order streams is 1.84 miles.

The area is located in the border zone of the Idaho Batholith and is classified as part of the Belt Super Group formation. The soils are moderately deep, well drained, loams to sandy loams, with surface layers containing an abundance of loessial silt. The watershed is completely forested with vegetation dominated by Grand Fir (Abies grandis) and its associated species.

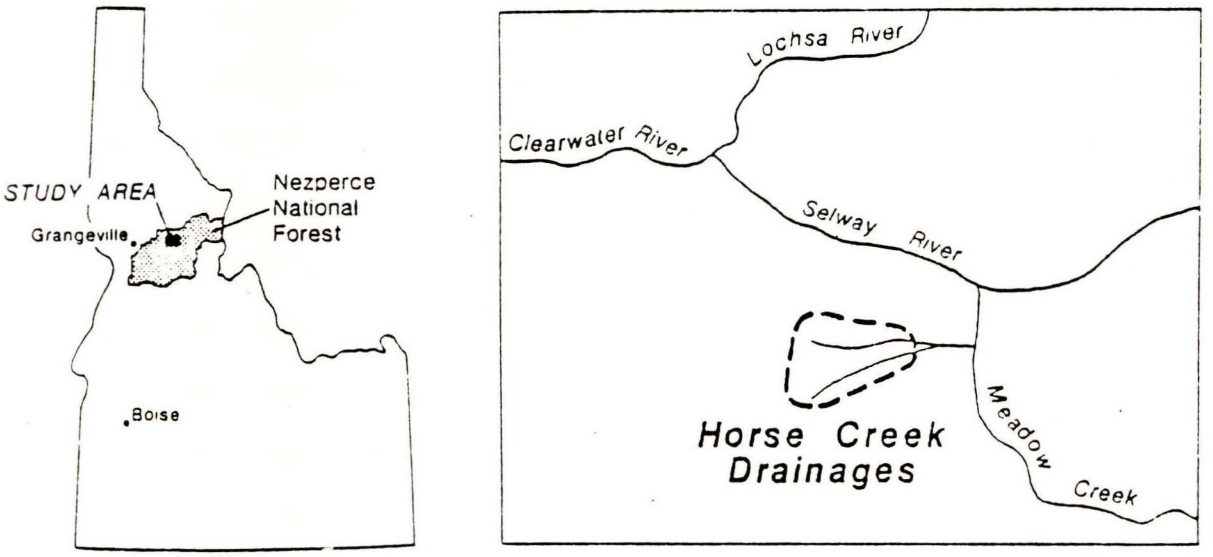

Figure 2a. Location of the Horse Creek Administrative Research Study Area. [1]/

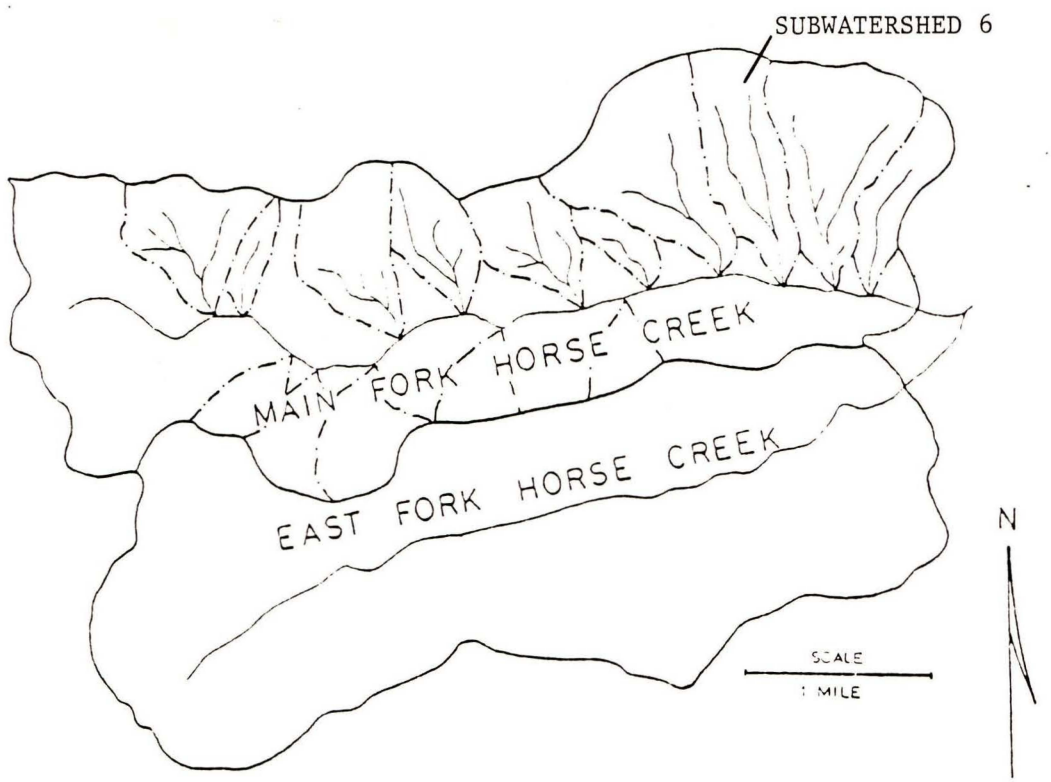

Figure 2b. The main and east fork drainage of Horse Creek.[1]/

[1]/adapted from USDA Forest Service Report, 1981.

The climate is influenced primarily by on-shore Pacific air masses. Average annual precipitation is 48 inches with 60 to 70 percent occurring as snowfall. Average annual temperature is 37° Fahrenheit. The wettest and coldest month occurs in January with the warmest and driest period in August. Peak runoff, which is produced by snowmelt, usually occurs in May or June with low flows normally occurring in late August. Average annual runoff on WS6 for the 1975-1979 period was 212 cfs-days which represents 19.7 area-inches.

Subwatershed 6 is managed as a control (undisturbed) area. An unimproved road crosses the top of the drainage. However, it is close to the upper boundary and is approximately 1500 feet (horizontal distance) from the stream head and does not appear to be contributing surface water and sediments to the stream channel. Therefore, the watershed was considered to be in a natural state with no roads present on the drainage.

METHODS

The methodologies employed in this study included three major phases: the input data collection and summarization into a compatible model format, the model calibration phase, and the testing for model sensitivity and with an independent input data set.

Data Collection and Summarization

A fairly intensive set of data are required to drive the model. Input requirements include climatological and watershed geometry data, soil hydraulic and physical characteristics, sediment particle size information, and channel and surface morphometric and energy-friction-particle detachment descriptors.

Climatic and Hydrologic Variables

The October 1, 1974, to September 30, 1975, water year was selected as the time period to be used for model testing. This water year was selected because the records for climatic and streamflow parameters were nearly complete (USDA 1975). A complete set of minimum and maximum temperature (°F), daily precipitation (in) and daily horizontal radiation (cal/cm^2) are needed to drive the model. Subwatershed 6 is not instrumented for collection of these data; therefore, the data were extrapolated from the nearest representative stations.

Precipitation data were obtained from the Lower Horse Creek weather station records. This station is located approximately 0.9 miles from the mouth of WS6. The difference in elevation between the mouth of WS6 and this station was considered insignificant (140 feet). Therefore, it was assumed that these data would provide a reliable estimate of precipitation on the study watershed.

Monthly precipitation records for the 1975 water year are essentially complete. However, in many cases the daily values are missing with lump sums recorded for time periods varying from several days to as long as a month. For example, lump sums of precipitation were recorded for January, February, August and September and for parts of March, April and June. Daily precipitation was estimated for these periods by applying a weighting function which distributed the lump sum over the time period in question according to the same daily proportions as the precipitation occurring during the same time interval at the Red River weather station.

Precipitation varies with elevation within a watershed. The model has a built-in linear adjustment equation for extrapolating precipitation

with elevation according to a defined function. The modeler inputs slope and intercept values for the equation and corrections for elevation are made internally. The maximum elevation change on WS6 (1220 feet) was not considered large enough to warrant development of the adjustment function; therefore, the slope and intercept coefficients were set at one and zero, respectively.

The model has the capability of distributing rainfall in a day according to defined storm characteristics. However, due to a lack of storm intensity and duration data this component was not utilized. Daily rainfall was distributed uniformly over the 24 hour period.

Daily minimum and maximum temperature data were used from the Lower Horse Creek weather station. Incomplete records were present for November, December, January, February, and March. Temperature data from the Buck Meadows weather station also located on the Horse Creek area were used to fill in the missing records. This station is located approximately 3.5 air miles from WS6 at an elevation of 5600 feet. A lapse rate correction factor of -3.0°F/1000 feet of elevation increase was used to correct temperature from the Buck Meadows station to the Lower Horse Creek Station.

Daily horizontal radiation data are not collected on the Horse Creek study area. The nearest station, which monitors solar radiation, is located at the Red River Ranger Station, located approximately 20 air miles from WS6. Horizontal radiation was missing from this station for a total of 68 days. The majority of these missing values occurred between January and October of 1975. The missing values were estimated by developing a ten year average value of daily radiation on a given date at that station.

Monthly potential evapotranspiration (PET) was estimated by the Thorntwaite method (Thorntwaite 1948), as presented in the SNOWSED Users Manual (Simons et al. 1981b). Unadjusted PET was calculated on a 30 day, 12 hour day basis with the equation:

$$EP = 1.6\ (10.0\ T/I)^{A} \tag{3}$$

where:

EP = unadjusted PET in cm/month
T = monthly temperature index in °C
I = annual heat index (summation of 12 monthly values)
A = coefficient determined empirically

The equation used to determine A was

$$A = 6.75 \times 10^{-7}(I^3) - 7.7 \times 10^{-5}(I^2) + 1.792 \times 10^{-2}(I) + 0.49239 \tag{4}$$

where:

A = the coefficient
I = as defined in equation (3)

The unadjusted PET was corrected for month and day length according to procedures presented in Thorntwaite (1948).

Watershed Geometry Data

SNOWSED was designed to model drainage systems which are represented as a series of channel segments and contributing planes. Input requirements for the geometric characterization of the watershed include slope, average elevation, length and width of each plane unit, the length and slope of each channel segment and the coefficients of the power functions which describe the relationships between wetted perimeter, top width of channel flow and cross sectional area of flow.

The procedures for delineating watershed planes and segments and associated information which were used in this study are outlined in the

SNOWSED User's Manual (Simons et al. 1981b). The study watershed was separated into a two plane one channel segment configuration for model testing (Figure 3). Topographic maps were used to obtain plane slope, elevation, length and width data. Channel length, slope and cross section data were obtained from field measurements during August of 1981. Channel length and slope were measured with a 100 foot steel tape and Abney level. Channel cross sections were surveyed using standard surveying techniques.

Three equally spaced cross sections were surveyed in the upper portion of the channel segment and three in the lower portion. The cross section data were used to develop coefficients for equations (1) and (2).

The α_1, β_1, α_2, β_2 coefficients were developed for each cross section and a weighted average coefficient of each was determined for the channel section. The coefficients were weighted according to the length of channel represented with subsequent calculation of an average for each coefficient. The data used for these calculations are presented in Appendix A.

Vegetation Data

Vegetation information was obtained from existing records and by field observation. Canopy cover density for the two planes was estimated to be 68 percent from data collected by Haygreen (1980). Ground cover density was measured on site along randomly located transects on the surface planes. Six transects with 100 equally spaced points (one foot interval) were measured in each plane unit. Sample points were classified as covered or bare mineral soil (cover implied vegetation, litter, duff, downed timber or rock.).

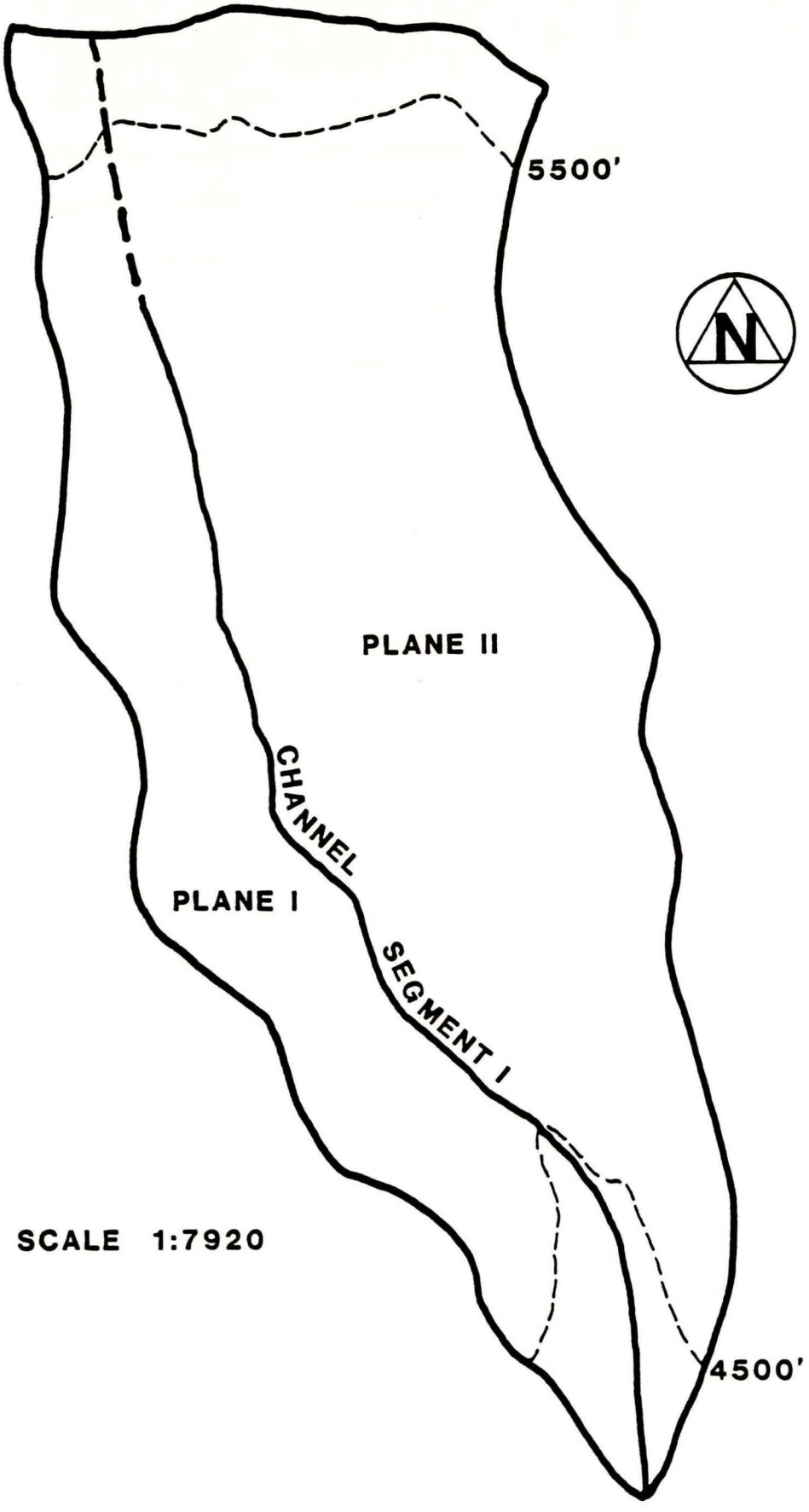

Figure 3. Diagram of watershed 6 with two planes and one channel segment geometry.

Sediment Particle Size Data

Channel bed materials were collected at random points along the channel segment. Particle size analysis was conducted on these samples using standard sieving techniques. Since only one set of particle size data are input in the model per channel segment and only one segment was modeled, data from the sample nearest the gauging station were used (Appendix B).

Model Calibration

The primary goal of calibration in this study was to generate simulated water and sediment yield data which closely approximated observed data at the mouth of WS6. The trial and error adjustment method of model calibration was employed to calibrate the model with 1974-1975 streamflow and sediment data from the watershed. The original objective of this phase of the project was to calibrate the model on an annual basis. However, in an effort to conserve computer costs, the calibration process was limited to a 90-day period when the snowmelt hydrograph occurred (April 18 - July 16, 1975).

The simulated output parameters of total water yield, maximum flows and total sediment yield were used as best fit criterion. The limits for an acceptable fit between the observed and simulated values of these parameters was ±10 percent. In addition, minimum flows and two subjective criterion, time to peak flow and general hydrograph shape were used to evaluate the success of model calibration.

Several input parameters were adjusted during model calibration. These parameters and range of values are presented in Table 1. A complete list of model input parameters are presented in Simons et al. 1981a.

Sensitivity Analysis and Independent Data Testing

Parameter perturbation analysis was conducted to ascertain how the model responded to changes in selected input parameters. Once the model was simulating in the best fit mode two input parameters were separately perturbed several times and subsequent changes in simulated output were determined. The parameters selected for this analysis were intrinsic permeability and channel detachment coefficient. Intrinsic permeability was chosen because it was hypothesized that this parameter would have an important impact on total water yield, and timing of the subsurface flow component contribution to channel flow. Also the on-site value of this parameter is usually unknown. The channel detachment coefficient is important because it is used in calculating the amount of bedload sediments which are detached and transported within the channel flow-energy-sediment supply system. On-site values for this parameter are also usually not available.

Once the calibrated mode of the model was attained for the 90-day snowmelt hydrograph period (April 18 - July 16, 1975), the model was run for the entire October 1, 1974, to September 30, 1975, period. The pre- and post-snowmelt flow periods were considered the independent data testing periods. Comparisons between simulated and observed hydrograph data were made to evaluate model performance during the non-calibration time periods of the study.

Table 1. A listing of some of the model input parameters and range of values used during model calibration.

Parameter	Description	Range of Values	Calibrated Value
PERMX	Instrinsic permeability (ft^2)	0.85×10^{-6} to 8.5×10^{-8}	8.5×10^{-8}
WETK	Hydraulic conductivity (in/hr)	1.5 - 3.0	3.0
POROS	Porosity	0.4 - 0.5	0.5
SI(I)	Initial soil moisture content (percent)	0.01 - 0.80	0.01
SAVE(I)	Average capillary section (in)	4.0	4.0
% BASE	Baseflow as a percent of total annual water yield	0.15	0.15
BASE	Mean daily base flow for month of lowest Q (cfs/mi^2)	0.31	0.31
SOLDEP1	Soil depth (in)	30	30
SOLDEP2	Percent of subsurface flow reaching channel segment	0.80 - 0.95	0.95
XN	Manning's n for channel	0.06 - 0.07	0.067
CHDOF	Channel flow sediment detachment coefficient	0.01	0.01
DATIS	Date snowpack is isothermal	1 - 129	70
TCOEF	Transmissivity coefficient	0.24	0.24

RESULTS AND DISCUSSION

The model was successfully calibrated for the April 18 through July 16, 1975, runoff period. Initial calibration involved simulating total water yield, peak flow, time to peak flow, within acceptable limits. The second phase of calibration was conducted using the initial calibrated mode of the model with subsequent calibration to obtain adequate simulation of total sediment yield.

Input Parameters

Several input parameters were adjusted during the two phases of model calibration. A listing of some of these parameters and final calibration values are presented in Table 1. Values for many input parameters were obtained from existing data. However, starting values for several of the variables were unknown. The values for certain unknown variables such as intrinsic permeability, average capillary suction, initial soil moisture, Manning's "n," soil particle detachment coefficients, saturated hydraulic conductivity, and others were estimated using local geologic, edaphic, and hydrologic information plus the procedures outlined in Simons et al. (1981b). Using the guidelines presented in Simons' report, the input parameters expected to have the greatest impact on simulation of water and sediment yields were adjusted until the simulated output for water and sediment yield were within ±10 percent of the observed values.

90-Day modeling Period

Simulation of total water yield to within ±10 percent of the observed runoff for the April 18 to July 16 snowmelt runoff season was not difficult to obtain. Observed water yield for this period was 308 ac-ft,

and the calibrated simulated yield was 327 ac-ft (within 6.2% of the observed, Table 2). The input parameters which appeared to have a significant effect on simulated total water yield (other than climatic data) were initial soil moisture saturation, isothermal date, percent subsurface flow reaching the channel, intrinsic permeability, and hydraulic conductivity.

Table 2. Observed and simulated values for selected flow and sediment variables for the 90-day modeling period.

Variable	Observed	Simulated	% Difference
Total water yield (ac-ft)	308	327	+ 6.2
Maximum flow (cfs)	5.83	5.82	- 0.2
Minimum flow (cfs)	0.284	0.126	-55.6
Time to peak (Julian day)	154	162	--
Total sediment yield (lbs)	10,810	10,675	- 1.2

Attaining a simulated peak flow for this period which matched observed peak flow within ±10 percent was comparatively more difficult. The observed hydrograph contained two major flow periods (Figure 4). The model simulated a comparable bimodal hydrograph; however, it was not possible to simulate both peaks within the ±10 percent criterion. Adjustments in input parameters produced similar changes in the two peaks, i.e. an increase in peak flow for the first peak was followed by an increase in the second peak. Throughout the calibration period the simulated second peak was consistently higher than the observed second

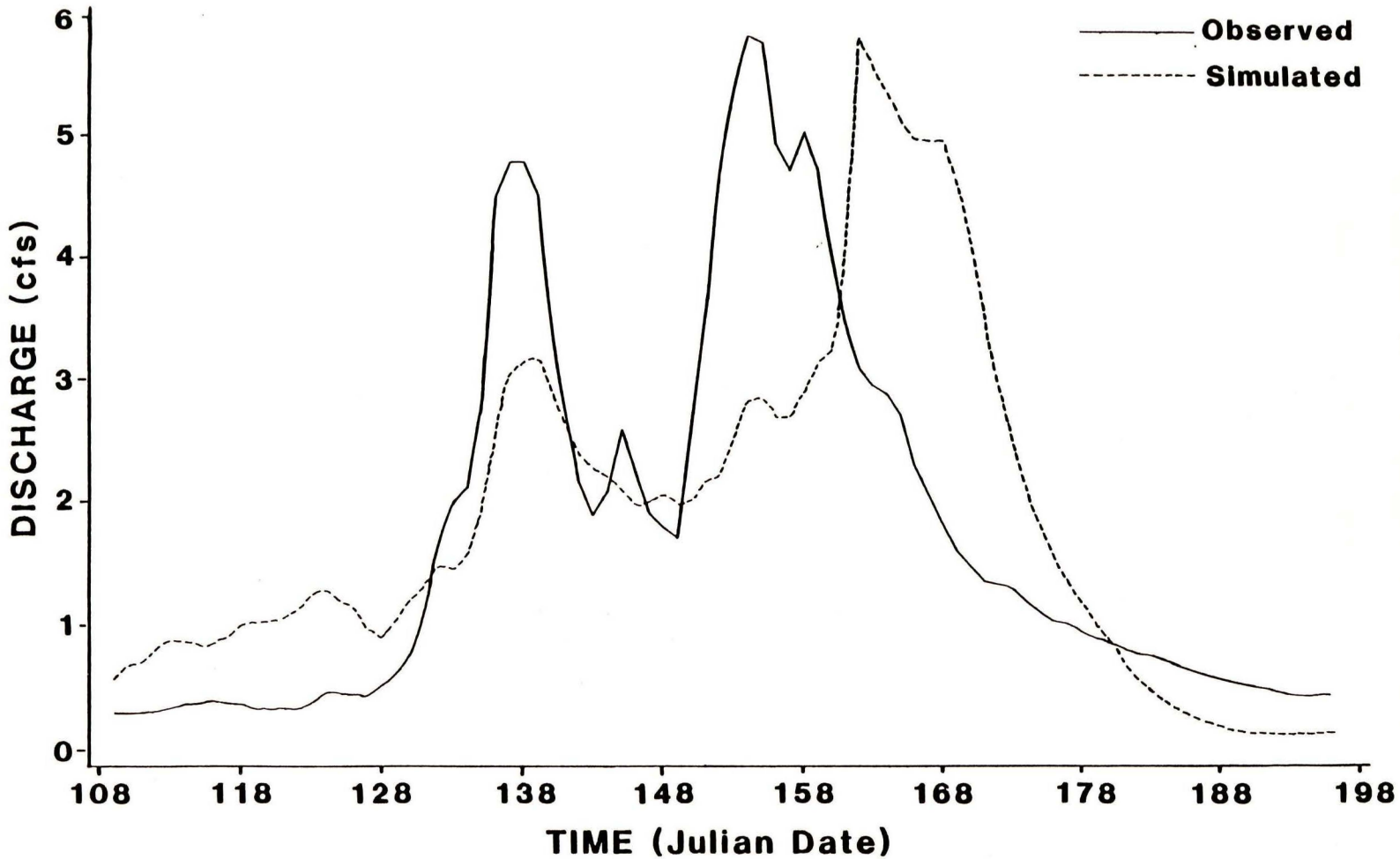

Figure 4. The simulated and observed hydrographs for watershed 6 during the April 18, 1975 (day 108) to July 16, 1975 (day 197) modeling period.

peak. Since the highest flows in a stream channel would most likely have the greatest influence in the potential for detaching and transporting sediments, the model was calibrated to obtain if possible a simulated flow for the second peak which was ±10 percent of the observed value. The final simulated peak flow was 5.82 cfs which was within 0.2 percent of the observed value of 5.83 cfs (Table 2). The input parameters which were adjusted to obtain this simulation were percent subsurface flow reaching the channel, intrinsic permeability, and hydraulic conductivity. A listing of these parameters and values used are presented in Table 1, plus the simulated and observed hydrographs are presented in Figure 4.

Simulation of the time to peak flow within ±10 percent of the observed was not possible (Figure 4). Simulated peak flow occurred on Julian day 162 where as observed peak flow occurred 8 days earlier on day 154 (Table 2). Several adjustments were made in the model input parameters which were expected to have the greatest impact on the timing of peak flow. Adjustments in input variables which can affect snowmelt was limited to those variables which characterize the physical characteristics (isothermal date and surface reflectability) of the snowpack and those variables which directly influence the snowpack surface - energy interface (percent canopy cover, transmissivity coefficient and percent snowpack shaded). Adjustments in variables which influence the routing of melt water also produced unsuccessful results. The final calibration run represents the best fit for timing of peak flows (Figure 4). The first of the simulated bimodal peaks was within two days of the observed peak during that portion of the runoff period.

After a fairly intensive unsuccessful attempt to correct the large discrepancy in simulating time to peak flow by adjusting the above variables, it was hypothesized that perhaps the input data for temperature and solar radiation was not representative of what had actually occurred on WS6 during the snowmelt period. These two variables provide the major energy sources for producing snowmelt in the SNOWMELT program, and both of these daily data were extrapolated from other stations; temperature from the Lower Horse Creek Station and Buck Meadows Station and solar radiation from the Red River Station. Because of the importance of these variables in the model for determining the amount of daily snowmelt and subsequent hydrograph, reasonably accurate daily temperature and solar radiation data are prerequisite to obtaining a simulated snowmelt hydrograph which closely fits the observed runoff. Additional illustration of the impact of these variables on the simulated hydrograph are presented in the independent data testing section of this report.

Once the hydrology portion of model calibration was completed, the second phase of calibration was conducted. This phase involved adjustment of input variables which could significantly impact the models ability to simulate sediment detachment and transport. The high infiltration rates and high hydraulic conductivity of the undisturbed forest soils on this watershed permit movement of most surface waters into and through the subsurface profile. As expected, the model did not simulate any overland flow on the surface planes during the period modeled. Without overland flow, sediment production from the surface planes is nonexistent. Given this consideration, it was assumed that all sediments delivered to the mouth of the watershed were produced in the

stream channels. Therefore, only those input variables which could affect channel erosion were manipulated during this phase of calibration.

The physical process functions, which estimate the amount of sediments eroded and transported in a channel, are presented in Simons et al. (1981a). The input variables of channel particle detachment coefficient and Manning's "n" are two of the parameters used in these functions for determining the amount of sediment that is eroded. These variables were adjusted to obtain a simulated total sediment yield in the 90-day period which was within ±10 percent of the observed yield. The initial estimate of 0.01 for the channel detachment coefficient proved to be adequate. Simulated yield with this value was close to the observed. Subsequent adjusting of Manning's "n" permitted a fine tuning of the initial estimate. The calibrated values of these variables are presented in Table 1. Also, the impact of changes in the channel detachment coefficient on sediment yield is presented in the sensitivity analysis section of this report.

The final calibrated form of the model (water and sediment) simulated a total sediment yield for the 90-day period of 10,675 lbs., which was within 1.2 percent of the observed yield of 10,810 lbs. (Table 2).

Sensitivity Analysis

Following completion of model calibration for the 90-day period, a parameter perturbation analysis was conducted to gain insight into the effects a defined change in an input parameter would have on simulated water and sediment yield. Several model input parameters were considered to be important in determining the degree of water and sediment produced by a physical process model. An initial objective of this

study was to change several of these variables at three to five levels to determine direct and interactive effects of these changes on model simulation. However, exorbitant computer costs prohibited application of this analysis. Therefore, it was decided to adjust two parameters for five different levels and determine the level of change in simulated total water yield, peak flow, and total sediment yield. Two model input parameters which are usually unknown but can significantly affect water and sediment movement on a watershed, are the intrinsic permeability of the subsurface porous medium and the channel particle detachment coefficient. These variables were chosen for the sensitivity analysis.

Intrinsic permeability which is expressed mathematically as

$$k = Cd^2 \tag{5}$$

where: k = intrinsic permeability (L^2)

C = shape factor (effects of stratification, packing, arrangement of grains, size distribution, and porosity)

d = average pore size of the porous medium (L)

is used in the subsurface flow routine of OVERLAND FLOW to quantitatively describe the effect of the inherent porosity characteristics of the subsurface medium on the rate of liquid movement through the medium. The results of adjusting this parameter for values which represented a range of porous medium from a gravelly texture to clayey sands ($1.28 \times 10^{-7} ft^2$ to $1.06 \times 10^{-12} ft^2$, respectively) are presented in Table 3. A 50 percent increase in k from the calibrated value ($8.5 \times 10^{-8} ft^2$) produced a 6 percent increase in total water yield and an 18 percent increase in total sediment yield. A 99 percent decrease in k from the calibrated value produced a 25 percent decrease in total water yield and 148 percent increase in total sediment yield. Apparently as k decreases, the model routes less subsurface water from the planes to the channel.

Table 3. The changes in simulated total water and sediment yield and peak flow as related to perturbations in intrinsic permeability and channel detachment coefficient for the 90-day modeling period.

Input			Output					
Parameter	Value	% change	Total water yield (ac-ft)	% change	Total sediment yield (lbs)	% change	Peak flow (cfs)	% change
Intrinsic permeability $(ft)^2$	1.70×10^{-7}	+ 100	356	+ 9	13,741	+ 29	8.4	+ 45
	1.28×10^{-7}	+ 50	346	+ 6	12,621	+ 18	7.3	+ 26
	8.50×10^{-8}*	0	327*	0	10,675*	0	5.8*	0
	4.30×10^{-8}	- 50	276	-16	7,489	- 29	3.8	- 34
	1.06×10^{-12}	- 99	247	-25	26,444	+148	28.2	+386
Channel detachment coefficient	0.001	-1000	--	--	1,706	- 84	--	--
	0.005	- 500	--	--	6,750	- 38	--	--
	0.010*	0	327*	--	10,675*	0	5.8*	--
	0.050	+ 500	--	--	20,124	+ 89	--	--
	0.100	+1000	--	--	22,917	+115	--	--

* Values for calibrated mode.

The increase in sediment yield associated with a low k value is most likely related to the increase in peak flows which occurred as k was decreased. Watersheds with less permeable material in the subsurface strata typically have more rapid response and higher flow compared to drainages with a more permeable flow material.

Peak flow fluctuated as k was changed (Table 3). The change in k of $1.70 \times 10^{-7} ft^2$ to $1.06 \times 10^{-12} ft^2$ produced an increase in peak flow from 5.8 cfs to 28.2 cfs with a subsequent 148 percent increase in total sediment yield.

Manipulation of the channel detachment coefficient produced significant changes in simulated total sediment yield. As expected, no change in the hydrograph occurred when this parameter was adjusted. This coefficient is used in the process functions in CHANNELROUTE which estimates the amount of sediment which can be detached, and is available for transport in the channel segment. A detailed explanation of the sediment detachment and transport functions used in the model are presented in Simons et al. (1981a). Changing this coefficient from 0.01 to 0.05 produced an 89 percent increase in yield (Table 3). As this parameter increases, simulated sediment yield increases.

The results of this analysis indicate that representative estimates of these parameters is essential if realistic simulation of the hydrograph and channel erosion processes are desired.

Independent Data Testing

The final testing of the model involved applying the calibrated form of the model to the Oct. 1, 1974 to Sept. 30, 1975 period. Climatic data for this period were input and an annual water year hydrograph was simulated.

The simulated and observed annual hydrographs are presented in Figure 5. The following discussion will address two major flow periods; Julian dates 273 to 108, pre-snowmelt, and Julian dates 208 to 273, post-snowmelt.

Simulated daily discharge for the pre-snowmelt period was not representative of the observed hydrograph. The rainfall events which were input during November (Julian days 305-334) produced simulated daily flows which were higher than the observed flows (Figure 5). Also, a significant runoff event was observed on the watershed on day 18. However, the model did not simulate flow during this period. The observed hydrograph on this day was most likely produced by a rain on snow event. The snowmelt program has a subroutine which uses threshold temperature values to determine whether input precipitation is snow or rainfall. If the minimum daily air temperature is $<32°F$ or if the daily maximum air temperature is $\leq 35°F$, precipitation is defined as snowfall. The actual minimum temperatures during this period were below 32°F but the maximum temperatures were above 35°F during the day when rainfall was occurring. Because of the low minimum temperatures the model was accumulating additional snowpack when, in actuality, rain on snow was producing streamflow.

The model also simulated daily snowmelt and streamflow during this pre-snowmelt period which was not observed on the watershed. The daily solar radiation data for this period which was extrapolated from the Red River Station was of sufficient magnitude to produce snowmelt; therefore, the model was simulating daily melting of the existing snowpack. However, actual melting of the snowpack did not occur for several days later than simulated melt. Apparently the solar radiation used for

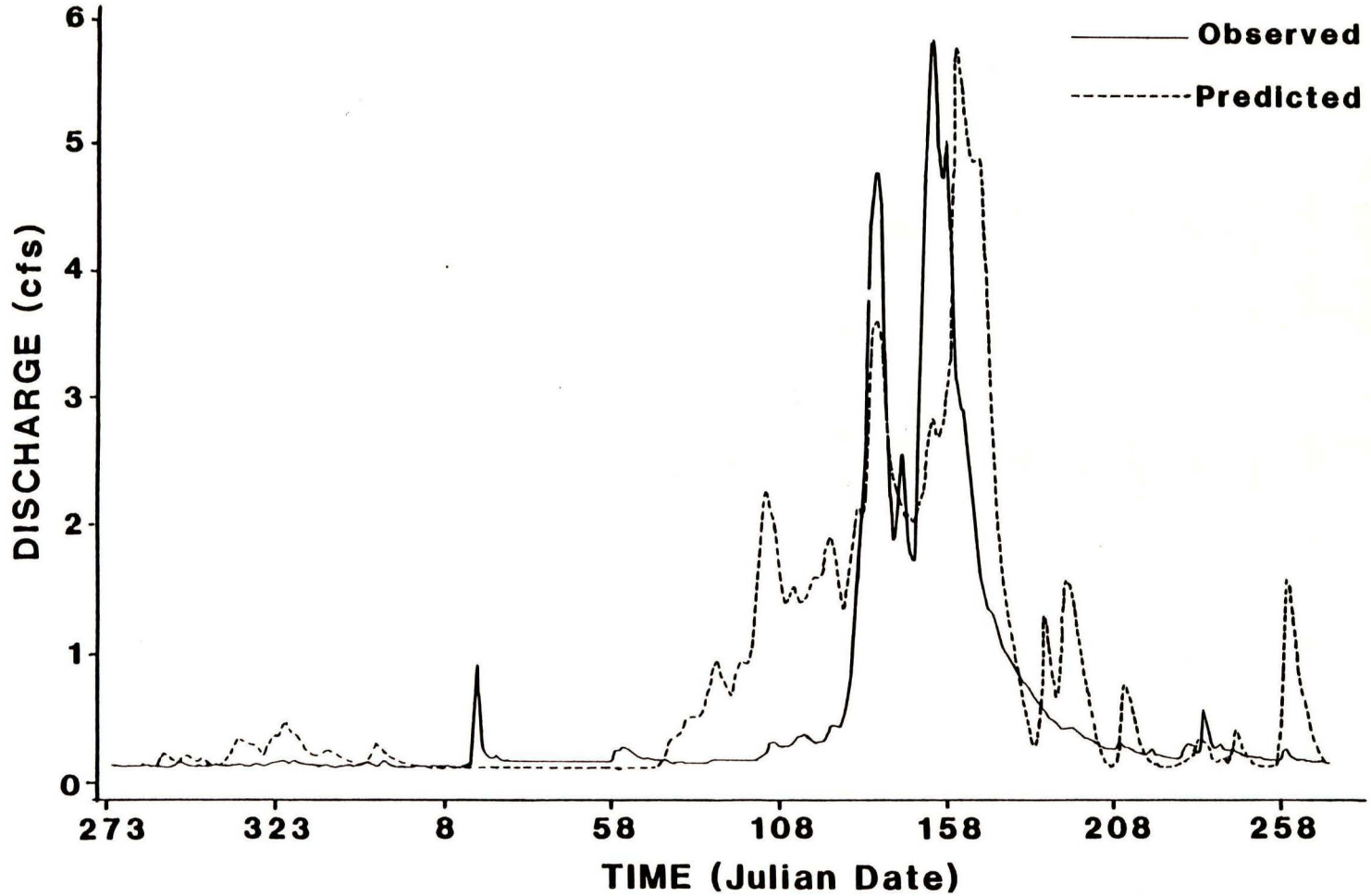

Figure 5. The observed and simulated hydrographs for watershed 6 for the 1975 water year.

modeling in the early spring was not representative of what actually occurred on the watershed.

The model simulated four major peak flows during the post snowmelt period which did not occur on the WS6 observed hydrograph (Figure 5). Precipitation data from the Lower Horse Creek Station indicated that rainfall events of sufficient magnitude to produce substantial flows occurred during these periods. The rainfall events input into the model which produced these simulated hydrographs were 1.39" - day 186, 1.73" - days 192-195, 0.96" - days 208-212, and 1.88" - days 258-260. If these storms actually occurred on the Horse Creek watersheds, significant increase in streamflow should also have occurred. Either the precipitation data from the Lower Horse Creek Station and/or the flow records from WS6 are in error. Investigation of the flow records of the other gauged subwatersheds and the Main Fork of Horse Creek revealed that none of Horse Creek streams indicated a significant increase in streamflow during these periods. A check of the Red River and Elk City precipitation records showed that no storms were recorded at these stations during the above periods. Apparently, the precipitation data at the Lower Horse Creek Station during the 1975 post-snowmelt is inaccurate. The model simulated significant hydrographs because of the bogus rainfall events which were input during the post-snowmelt period. Consequently, simulated and observed flow data were quite different.

Simulated annual water yield was 566 ac-ft, which is 37.7 percent higher (155 ac-ft) than the observed yield of 411 ac-ft (Table 4). Because of the suspected biases in the climatic data which was used during simulation, it is difficult to ascertain if this overprediction is

due to the model's inability to adequately simulate the hydrograph for the year, or due to inaccurate climatic data, or a combination of the two. Also, no attempts were made to calibrate the model for an entire year; therefore, some of the input parameters which were set for the 90-day snowmelt calibration period may have introduced some bias into the water budgeting for the year. Additional testing of the model for longer time periods with more representative climatic data is needed before any viable reasons can be given for the differences between simulated and observed annual water yield.

Table 4. Observed and simulated values for selected flow and sediment variables for the annual modeling period.

Variable	Observed	Simulated	% Difference
Total water yield (ac-ft)	411	566	+37.7
Minimum flow (cfs)	0.130	0.126	- 3.1
Maximum flow (cfs)	5.83	5.77	- 1.0
Time to peak (Julian day)	154	161	--
Total sediment yield (lbs)	11,144	11,145	- 0.01

Total simulated annual sediment yield was 11,145 lbs, which is one pound higher than the observed annual yield of 11,144 lbs (Table 4). It was originally hypothesized that because of the nonrepresentative peak flows during the July - September 1975 period, the simulated annual sediment production from the watershed would be much greater than the observed. Apparently when these simulated peak flows

occurred after snowmelt runoff, the model was simulating a sediment supply limited condition, i.e., the potential for sediment particle detachment and transport was high for certain size fractions during these peak flows; however, these size fractions were not available for transport. The existing bed load sediments had been removed during snowmelt runoff to an armoring size fraction; a typical occurrence on undisturbed forested watershed in northern Idaho.

SUMMARY AND CONCLUSIONS

The SNOWSED model simulated total water yield, peak flow, and total sediment yield within the ±10 percent of observed values for the 90-day, April 18 to July 16, 1975 period. It was not possible to adequately simulate the time to peak flow to coincide with the observed peak. Calibration of the model for this period with the two plane - one channel segment geometry configuration was not difficult to attain. The important fact that the watershed being modeled was in an undisturbed forested condition with high infiltration and high subsurface permeability most likely made calibration easier. With these conditions present the simulated overland flow component was nonexistent; therefore, the overland flow routing and surface sediment detachment and transport process functions were not used. Thus, the simulation processes were less complex.

Changes in the input variable intrinsic permeability (k) produced significant changes in water yield, peak flow and sediment yield. The on-site value for this parameter is usually unknown. However, if local site information pertaining to physical characteristics of the subsurface material is available a good estimate of this variable can be made.

Another unknown input variable, the channel detachment coefficient, was found to have a significant effect on sediment produced in a channel segment. As previously stated, simulated overland flow was nonexistent; therefore, all sediments produced during simulation were from the channel segment. The results of the sensitivity analysis indicated that an increase in the variable from 0.01 to 0.10 created a 115 percent increase in simulated sediment yield, indicating that the selection of a representative estimate of this variable is important. The value of this coefficient is related to the particle size and cohesive properties of the inherent sediments. The 0.01 value used for subwatershed 6 would be a reliable estimate for drainages with similar edapic, geologic and physiographic characteristics.

Operation of the model for the 1975 water year produced some interesting and perplexing results. The models inability to simulate a hydrograph which was similar to the observed streamflow during the pre- and post-snowmelt periods can be attributed to at least three major factors. The first factor pertains to the method of using threshold temperatures to distinguish between snow and rainfall events. Sometimes the model was simulating snowfall when rain was actually occurring. If a significant rain event occurs and the model interprets it as snowfall, then a storm hydrograph will not be simulated.

The second factor affecting simulation during the pre-snowmelt period related to using daily solar radiation from the Red River Station which is approximately 20 miles from the study watershed to represent what was occurring on the Horse Creek drainage. The model simulated higher daily snowmelt with higher flows than was observed during this period. The increased melt probably occurred because the daily solar

radiation data which is the major energy source for snowmelt in the model was higher than what had actually occurred on the watershed.

The third factor which influenced the simulated hydrograph after the snowmelt season involved the use of questionable daily rainfall data. The model was responding to several rain events which should have produced increased streamflow in the Horse Creek watersheds. However, no significant responses were observed on any of the Horse Creek drainages.

If good simulation of daily flows are desired, then representative local climatic data are needed. Also, reliable daily precipitation data is prerequisite to adequate simulation of total water yield, peak flows and total sediment yields.

The SNOWSED model was tested on a 256 acre, undisturbed, forested watershed with one year of climatic data. The results in the context of simulation of reliable water and sediment yield were encouraging. Additional testing of this comparatively new, complex, physical process model is recommended before this model is used for planning purposes.

Additional information pertaining to testing of the SNOWSED model at Horse Creek will be presented in a Master of Science thesis which was conducted as part of this study.

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APPENDIX A

Coefficients for the wetted perimeter (P) and top width (T) of flow for the functions $P = \alpha_1 A^{\beta_1}$ and $T = \alpha_2 A^{\beta_2}$.

Channel Transect	Wetted Perimeter α_1	β_1	Top Width α_2	β_2
1	3.942	0.455	3.735	0.449
2	3.444	0.539	3.207	0.520
3	3.580	0.479	3.392	0.470
4	3.425	0.480	3.107	0.459
5	4.931	0.402	4.868	0.388
6	3.797	0.503	3.431	0.512
Average	3.818	0.477	3.598	0.466

APPENDIX B

Channel bedload sediment and soil surface particle size distribution data used for the one channel segment and two plane configuration.

Particle Size (mm)	Cummulative Distribution (% finer by weight)
Bedload	
0.250	2.90
0.495	7.40
1.00	11.80
2.00	19.20
4.75	33.10
12.70	39.30
19.10	46.50
38.10	55.60
50.80	100.00
Soil Surface (mm)	
0.177	1.10
0.250	1.12
0.500	19.62
1.00	60.22
2.00	100.00